CHEMICAL PRETREATMENT AND THERMOPHILIC COMPOSTING PROCESS FOR RAPID BIODEGRADATION OF RICE STRAW

by

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DEDICATION

This thesis is dedicated to my wife Sepeideh and my family. This work is also dedicated to my lovely children Sana and Ali Reza.

May Allah grant them long life, health, knowledge and bright their future.

AMIN

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LIST OF ABBREVIATION

TT	Treated-Thermophilic condition
CO	Carbon Monoxide
MC	Moisture of Content
PM_{10}	Particulate Maters, less than 10 micrometers in diameter
RSM	Response Surface Method
CCD	Central Composite Design
CCME	Canadian Council of Ministers of the Environment
OM	Organic Matter
EC	Electrical Conductivity
TOC	Total Organic Carbon
COD	Chemical Oxygen Demand
SCOD	Soluble Chemical Oxygen Demand
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
C:N	Carbon to Nitrogen ratio
GI	Germination Index
MSW	Municipal Solid Waste
LHW	Liquid Hot Water

LCW	Lingo Cellulosic Waste
DOC	Dissolved Organic Carbon
VS	Volatile Soluble
DOE	Design of experiment
PRESS	predicted error sum of squares
CV	Coefficient of Variation
CCF	Central Composite Face-centered
CCC	Central Composite Circumscribed
CCI	Central Composite Inscribed
UM	Untreated-Mesophilic condition
UT	Untreated-Thermophilic condition
TM	Treated-Mesophilic condition
SEM	Scanning electron micrographs
EDX	energy dispersive X-ray
MPN	Most Probable Number
APHA	American Public Health Association
USEPA	United States Environmental Protection Agency
WSE	Water soluble extract
ICP	Inductively Coupled Plasma
ANOVA	Analysis Of Variance
QA/QC	Quality Assurance/Quality Control

PROSES PRA-OLAHAN KIMIADAN PENGKOMPOSAN TERMOFILIK DALAM BIODEGRADASI PANTAS JERAMI PADI

ABSTRAK

Jerami padi adalah salah satu sumber yang boleh diperbaharui di dunia. Sehingga kini, pembakaran terbuka merupakan amalan biasa sebagai pelupusan muktamad jerami padi di banyak negara Asian. Pencemaran udara yang dihasilkan daripada pembakaran terbuka ini boleh memberi kesan buruk pada penglihatan, kesihatan manusia, dan kualiti udara serantau. Bio-transformasi jerami padi kepada produk bernilai adalah satu penyelesaian yang ekonomi dan mesra alam untuk menyelesaikan masalah ini. Walau bagaimanapun, masalah utama dalam transformasi jerami padi adalah sifat tidak terbiodegredasinya. Kadar bio-pengoksidaan bahan hidrokarbon dalam kedaan pepejal meningkat apabila bahan berubah ke bentuk cecair. Begitu juga, pengkomposan bahan lignen selulos meningkat secara signifikan dalam keadaan termofilik. Oleh itu, kajian ini tertumpu kepada pengurangan masa proses pengkomposan jerami padi dengan menggunakan pra-olahan termo-kimia, beroperasi dalam keadaan thermofilik. Penyelidikan ini mengkaji keadaan operasi proses pra-olahan thermo-kimia, mengoptimumkannya dan menentukan pengaruh keadaan termofilik dalam perkomposan pra-olahan jerami padi.Tujuan kajian adalah untuk pengoptimuman proses pra-olahan termo-kimia, mengkaji pengaruh proses pra-olahan pada kestabilan, kematangan dan meningkatkan proses pengkomposan jerami. Pengaruh keadaan mesofilik dan

thermofilik juga dikaji. Teknik reka bentuk statistik menggunakan perisian Reka bentuk-Pakar menunjukkan bahawa penggunaan Kaedah Permukaan Respon (RSM) berdasarkan pada Reka bentuk Komposit Tengah (CCD) adalah realistik untuk kajian serentak pengaruh pembolehubah proses pada nilai kebolehlarutan jerami padi dalam pra-olahan proses termokimia dan interaksi mungkin antara mereka. RSM adalah peranti yang boleh dipercayai untuk merangka, memodel matematik dan mengoktimum keterlarutan jerami padi dalam reaksi termokimia. Kecekapan lima bahan kimia (NaOH, KOH, $Ca(OH)_2$, H_2SO_4 dan H_3PO_4) dalam kebolehlarutan jerami padi juga dibandingkan. Keputusan analisis optimum pra-olahan menunjukkan, keterlarutan maksimum jerami padi, sebanyak 82,40%, telah diperolehi menggunakanNaOH pada 200° C, 180 min dan 0.6 g NaOH/g. Kecekapan pra-olahan NaOH adalah34.47%, 60.51%, 76.90%, dan 73.90% lebih tinggi berbanding KOH, $Ca(OH)_2$, H_2SO_4, and H_3PO_4. Dapatan kajian ini menunjukkan bahawa integrasi pra-olahan termokimia NaOH padakeadaan proses pengkomposan termofilik boleh meningkatkandengan ketara kadar tindak balas kompos dan memendekkan kitaran pengkomposan ke 9 hari. Tahap parameter kompos pada hari ke 9 tersebut adalah hampir sama dengan tahap yang termaktub dalam Standard British Majlis Menteri-Menteri Alam Sekitar Canada (CCME).

CHEMICAL PRETREATMENT AND THERMOPHILIC COMPOSTING PROCESS FOR RAPID BIODEGRADATION OF RICE STRAW

ABSTRACT

Rice straw is one of the abundant renewable resources in the world. Until now, open field burning remains a common practice in many Asian countries for the final disposal of rice straw. The emitted pollutants from open burning of rice straw may cause adverse impact on visibility, human health, and regional air quality. Bio-transformation of rice straw to value products is an economical and environmental friendly solution for this problem. However, one of the main problems in rice straw transformation is its non-biodegradability. The bio-oxidation rate of hydrocarbon compounds in solid state increases after such compounds transform into solution forms. Similarly, the composting of lignocellulose materials significantly enhances under thermophilic conditions. Therefore, this study focuses on time reduction of the rice straw composting process by using thermochemical pretreatment and operation under thermophilic conditions. This study investigates the operational condition of the thermochemical pretreatment process, optimize the thermochemical pretreatment, and determine the influence of thermophilic condition on the composting of pretreated rice straw. The objectives of this research are for optimization of thermochemical pretreatment process, studying the effect of pretreatment process on the stability, maturity and enhancing of rice straw composting process. The influence of mesophilic and thermophilic conditions was also investigated.Based on the statistical design technique in Design-Expert, the use of the response surface method (RSM) based on Central Composite Design(CCD) is realistic for a simultaneous study of the effects of process variables on the solubility of rice straw in the thermochemical pretreatment process and the possible interaction between such variables. RSM is a reliable tool used for designing, mathematical modeling, and optimizing the solubility of rice straw in thermochemical reactions. The efficiencies of five chemicals (NaOH, KOH, $Ca(OH)_2$, H_2SO_4 and H_3PO_4) on the solubility of rice straw were compared with one another. According to the results of the pretreatment optimization analysis, the maximum solubility of rice straw is 82.40%, which was obtained using NaOH at 200 °C for 180 min with 0.6 g NaOH/g. The efficiency of NaOH pretreatment was 34.47%, 60.51%, 76.90%, and 73.90% higher compared with those of the KOH, $Ca(OH)_2$, H_2SO_4, and H_3PO_4 pretreatments. The findings of this research indicate that the integration of the NaOH thermochemical pretreatment with the thermophilic conditions of the composting process can significantly enhance the composting reaction rate and shorten the composting cycle to 9 days. The level of compost parameters obtained on the ninth day are almost similar to the level published by the British Standard and Canadian Council of Ministers of the Environment (CCME).

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Rice straw is the main bio-waste among the agricultural residues in the world(Kim and Dale, 2004). Rice (*Oryza)* is a monocotyledon plant with two cultivated species, namely, *Oryza sativa* and *Oryzaglaberrima*, which originate from Asia and Africa, respectively. *O. sativa* is commercially spread in 112 countries, whereas *O. glaberrima* is planted only in West Africa (Lim et al., 2012).

China and India produce more than 90% of the total produced rice in Asia. In 2009, 196.7 and 133.7 million tons of paddy rice were produced from 29.8 and 41.9 million ha of agricultural farm in China and India, respectively. Malaysia produces approximately 2.6 million tons of paddy rice annually, which consequently releases around 2.6 million tons of straw residues (FAO, 2012).

Rice straw is the stalk of the rice plant that is usually left on the field as a waste product after rice grain harvest(Lim et al., 2012).The total demand for rice straw is predicted to increase from 422 million tons in 2007 to 450 million tons in 2020 (Timmer et al., 2011; Lim et al., 2012).

Rice husk and straw are two major by-products of rice cultivation, comprising approximately 20% and 50% of the dry weights of grain yield, respectively. Although some rice mills use husk for electrical power generation, most husks and straw are disposed at landfills or burned at open fields. Rice straw is less frequently used than husks and is uneconomical because it requires collection, pretreatment, and even storage (Pandey et al., 2010).

Open field burning remains a common practice in many Asia countries for the final disposal of rice straw (Abdelhamid et al., 2004; Daño and Samonte, 2008; UNEP, 2009). In Thailand, after rice harvest, 48% of rice straw residues are burnt, 30% are not used, 15% are used as animal feed, and 7% are used in other activities. India and the Philippines burn 23% and 95% of the total rice straw residues produced, respectively (Gadde et al., 2009)

Open burning is an uncontrolled combustion process that emits many pollutants, such as soot, particulate matter (PM), carbon dioxide (CO_2), carbon monoxide (CO), unburnt carbon, nitrogen oxides (NO_x), sulfur dioxide(SO_2), methane (CH_4), volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-*p*-dioxins, and polychlorinated dibenzofurans, into the atmosphere (Estrellan and Iino, 2010). According to a study on rice straw burning in Taiwan, rice straw burning is a source of approximately 6.3% to 24.6% of total PAHs (Lai et al., 2009).

Pollutants emitted by open burning of rice straw have a significantly adverse impact on visibility, human health, and regional air quality. $PM_{2.5}$ concentrations reached 110.3 and 234.1 μg m^{-3} after rice straw harvest in Korea and Taiwan, respectively

(Estrellan and Iino, 2010). Moreover, an increase in PM_{10} and some organic and inorganic pollutant concentrations has been reported after an open burning of rice straw in Spain (Viana et al., 2008).

In Malaysia, rice fields are concentrated in the north. These areas produced over 1.6 million tons of rice grain in 2008. After harvest, rice straw is left in the paddies and disposed of via landfill and open burning (Shafie et al., 2012). In the northern region of Malaysia, only two rice mills use 86,400 tons of rice husks per year for energy production, one of which generates 470 kW of electricity (Shafie et al., 2012).

Composting is a well-known bio-refiner process used for the rapid bio-transformation and bio-oxidation of organic matter, such as municipal solid waste, garden waste, and rice straw, as well as for environmental and economic purposes. In composting, readily biodegradable organic matter is metabolized by microorganisms as carbon and nitrogen sources. The final products of composting include mineralized compounds, composting by-products, and dead microbes (Wei et al., 2007).

Composting offers many advantages, including sanitation, volume reduction, and improvement of certain characteristics, such as a decrease in carbon-nitrogen ratio (C:N) (Abdelhamid et al., 2004). However, composting requires long process time, large space, and manpower (Raut et al., 2008). The biotransformation of raw materials into maturated compost via conventional composting requires two to six months. Therefore, reduction of the composting time is an interesting topic for research (Lin et al., 2009).

1.2 Problem statement

Rice straw residues comprise the most abundant by-products in paddies. The residue production rate increased in the past decades. For example, the quantity of rice straw waste increased from 310 million tons in 1990 to 377 million tons in 2005 (FAO, 2012). In many Asian countries, open burning in fields is a common practice for rice straw disposal, degrading the air quality of some areas (Abdelhamid et al., 2004; Daño and Samonte, 2008; Gadde et al., 2009; UNEP, 2009). For example, CO and PM_{10} concentrations increased from around 50 g km^{-2} to 1,000 kg km^{-2} after harvest season in central-south Taiwan (Yu et al., 2012).

A proper disposal of rice straw is sanitary, eco-friendly, and sustainable. Composting offers many advantages, including sanitation, volume reduction, and improvement of certain characteristics, such as decrease in C:N (Abdelhamid et al., 2004). However, some complex polymers in rice straw, such as lignocelluloses, make rice straw resistant to microbial attack and bio-transformation. Thus, rice straw bio-decomposition process rate decreases and as a result, rice straw composting requires long process time, large space, and manpower (Zayed and Abdel-Motaal, 2005; Raut et al., 2008). A suitable pretreatment process is essential to open up the matrix of lignocellulosic materials for enzymatic attack and efficient bioconversion.

Combining chemical and physical pretreatment processes significantly increases hemicellulose solubility rate and changes in lignin matrix, consequently providing improved accessibility of the cellulose for hydrolytic enzymes in microbial process such as composting process (Taherzadeh and Karimi, 2008; Hendriks and Zeeman, 2009). Therefore, it is expected that the chemical pretreatment of rice straw causes to reduce of composting process time.

1.3 Objectives

The main objective of this study is to enhance the efficiency of the biocomposting process of rice straw through thermochemical pretreatment by investigating the following:

i. To optimize the operating conditions of the thermochemical pretreatment process of rice straw;
ii. To determine the influence of pretreatment elements on the stability, maturity, and enhancement of the rice straw composting process; and
iii. To determinate the influence of mesophilic and thermophilic conditions on the stability, maturity, and enhancement of rice straw composting.

1.4 Scope of study

Thermochemical pretreatment is considered an efficient pretreatment for lignocellulosic materials prior to anaerobic digestion or enzymatic bio-transformation. However, thermochemical pretreatment has not been established well for the enhancement of solid waste composting. The application of a chemical-biological integrated process under thermophilic composting conditions which is proposed by this study, is claimed to be a novel method for the enhancement of the bio-oxidation rate of rice straw.

In this study, the resource materials used for composting consist mainly of rice straw and cattle manure. Rice straw samples collected from a rice field at Nibong Tebal, Pulau Penang, Malaysia. Fresh cattle manure took from a local cattle farm. The experiments conducted in three steps. First, the selected physicochemical properties of the raw composting materials determined. Second, the optimum conditions of the thermochemical pretreatment of rice straw clarified on a bench scale of varying conditions. Finally, the effects of the thermochemical pretreatment of rice straw, thermophilic composting conditions, and interaction of such conditions on enhancing the stability and maturity of rice straw compost evaluated in four laboratory scale composting reactors. Temperature, EC, pH, OM, TOC, TKN, SCOD, C:N, GI, and most probable number (MPN) monitored during the composting period as stability and maturity indices.

Multivariable analysis of central composite design (CCD) under response surface method (RSM) has been widely used in empirical studies on the relationship between one or more actual responses, such as solubility, on the one hand, and a number of input variables, such as time, temperature, and chemical concentration, on the other. RSM used in the optimization section of the present study to identify the optimum conditions for enhancing rice straw solubility by analyzing the relationships among a number of parameters that affect the overall process. SCOD considered a suitable indicator for evaluating the soluble fraction of rice straw.

1.5 Thesis organization

This thesis consists of five chapters. Chapter 1: Introduction presents the common practices for the disposal of rice farm residual wastes, the chemical composition of straw, the composting process, and the pretreatment of rice straw. This chapter also explains the problem statements that justify the need for this study as well as the research objectives.

Chapter 2: Literature Review provides an overview of the pretreatment of lignocellulosic materials, rice straw composting, the technical aspects of composting and design, modeling, and optimization of process parameters.

Chapter 3: Materials and Methods describes in detail all the materials and procedures, sampling, experimentation, chemical analysis, quality control, and data analysis used in this study. Moreover, this chapter explains the statistical methods used in this study.

Chapter 4 and Chapter 5: Results and Discussion, which are the most important part of this thesis, are divided into three main sections. The first section illustrates the physicochemical properties; the second section discusses the results of the alkaline and acid pretreatments of rice straw; and the third section evaluates the results of the composting.

Chapter 6: Conclusions and Recommendations present the conclusions and recommendations for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Approximately half of the world's population consumes rice as a staple food. Over 90% of the world's rice is produced by Asia. China (28.7%) and India (19.5%) are the two largest rice producers in the world (Table 2.1), but their exports have decreased because of high population and local demand for rice.

Table 02.1: Production quantity of paddy and estimated quantity of rice straw and rice husk

Regions	Harvested quantity (million tons)	Estimated rice straw [a] (million tons)	Estimated rice husk [b] (million tons)
Africa	24.51	24.51	4.90
Americas	38.10	38.10	7.62
Asia	618.24	618.24	123.65
China	196.68	196.68	39.34
India	133.70	133.70	26.74
Indonesia	64.40	64.40	12.88
Bangladesh	47.72	47.72	9.54
Vietnam	38.90	38.90	7.78
Europe	4.10	4.10	0.82
Oceania	0.29	0.29	0.06
World	685.24	685.24	137.05

[a] with wet residue ratio of 1
[b] with wet residue ratio of 0.20
Source: Lim et al., 2012

Moreover, their economic growth has caused a change in people’s diet and an increased consumption of rice (Lim et al., 2012).Total rice consumption is expected to increase from 422 million tons in 2007to 450 million tons in 2020 (Timmer et al., 2011; Lim et al., 2012).

2.2 Application of rice straw

Half of the dry weight of the rice plant consists of straw. Therefore, farmers prefer to openly burn straw in fields because straw is non-readily-biodegradable and has negative effects on field productivity and because burning is the cheapest and fastest method (Pandey et al., 2009).

Direct application of rice straw to soil leads to several crop problems, such as plant diseases. Open burning of rice straw residues is a fast, cheap, and effective process for rice straw disposal. Collection of rice straw after harvest and its incorporation into soil is an attractive, albeit uneconomical, activity for rice grower (UCDavic, 2012). Therefore, open burning remains a common practice for rice straw disposal in Australia, France, Indonesia, Italy, Malaysia, Myanmar, the Philippines, Thailand, and California (Dehir et al., 2003). Consequently, valuable organic matter and nutrients in rice straw are lost, and toxic and hazardous pollutants, which may be carcinogenic, are emitted into the atmosphere (Gadde et al., 2009).

Rice straw residues are suitable raw materials for many activities, as shown in

Figure 2.1. However, only few methods are used in the industrial scale because of non-environmental-friendly, technical problems, and non-economically attractive aspects (UCDavic, 2012).

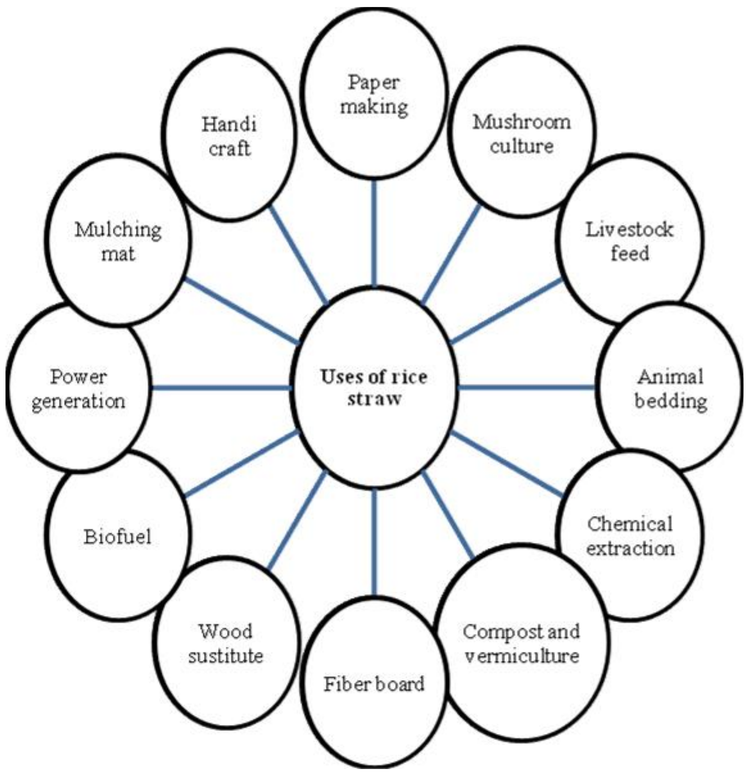

Figure 2.1: Different application of rice straw (Source: UCDavic, 2012)

In Thailand, after harvest, 48% of rice straw residues are burnt, 30% are not used, 15% are used as animal feed, and 7% are used in other activities (see Figure 2.2) (Gadde et al., 2009).

Rice is a highly protected crop in a strategically important industry in Malaysia. Malaysia produces approximately 2.6 million tons of paddy rice annually (FAO, 2012).

Based on use estimation in Table 2.2, Malaysia produces approximately 2.6 million tons of wet straw residues and 1.3 million tons of dry straw annually.

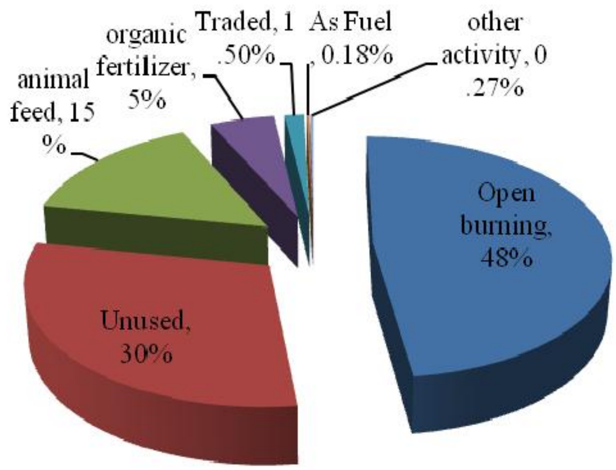

Figure 2.2: Various application of rice straw in Thailand(Source: Gadde et al., 2009)

Air pollution indices generally increase during harvest seasons in northern Malaysia because of the open burning of rice straw residues. Per ton of rice straw emits 893.9 kg of CO_2, and thus, approximately 2,323,360 tons of CO_2 is released to the atmosphere (Sashikala and Ong, 2009). Table 2.2 shows the emission factors for open-field burning of rice straw, wherein CO_2 comprises the largest amount of emissions.

Table 02.2: Emission factor for open burning of rice straw

CO_2 (g/Mg)	CO (g/Mg)	CH_4 (g/Mg)	NH_3 (g/Mg)	NO_x (g/Mg)	SO_x (g/Mg)	PM_{10} (g/Mg)	$PM_{2.5}$ (g/Mg)
1,171,500	32170	770	0	2,800	760	3,470	3,230

(Source: Sashikala and Ong, 2009)

Plate 2.1 and Plate 2.2 show an open-field burning of rice straw residues in a rice field (Gadde et al., 2009). Table 2.3Table 20.3 shows the estimated air pollution emissions from open burning of rice straw in India, Thailand, and the Philippines.

Plate 20.1: Open field burning of rice straw in a rice field

Plate 02.2: Result of rice straw open field burning

According to a study on rice straw burning in Taiwan, rice straw burning is a source of approximately 6.3% to 24.6% of total atmospheric particulates and polycyclic aromatic hydrocarbons (Lai et al., 2009).

Table 20.3: Air pollution emissions from open burning of rice straw in India, Thailand and Philippines (Source: Gadde et al., 2009)

Name of Pollutant	Unit	India	Thailand	Philippines
CO_2	Mg	16,253,012	12,206,603	11,850,034
CH_4	Mg	33,359	10,033	9,740
N_2O	Mg	779	585	568
CO	Mg	386,287	290,116	281,641
NO_x	Mg	34,510	25,918	25,161
SO_2	Mg	22,264	16,721	16,233
Total particulate matter (TPM)	Mg	144,719	108,689	105,514
Fine particulate matter ($PM_{2.5}$)	Mg	144,162	108,271	105,108
PM_{10}	Mg	41,189	30,935	30,031

(Source: Gadde et al., 2009)

In Malaysia, rice fields concentrate in the north. After harvest, rice straw is left in the paddies and disposed of via landfill and open burning (Shafie et al., 2012). In the northern region of Malaysia, only two rice mills use 86,400 tons of rice husks per year for energy production, one of which generates 470 kW of electricity (Shafie et al., 2012). Fuel cost is an important factor in feasibility studies on biomass energy generation plant projects. The cost of produced energy is relatively high when a power plant uses low-density biomass wastes, such as rice straw, because of the high cost of transportation (Delivand et al., 2011).

According to a study in Thailand, the cost of rice straw for power generation is not competitive with coal but comparable with other biomass (Suramaythangkoor andGheewala, 2010). Japan produces more than 9.4 million tons of rice straw and consequently approximately 13.545 bio-wastes (1.43%) annually. According to a similar study, the cost of electricity generated from rice straw is more than double the current price of electricity (Matsumura et al., 2005).

Rice straw can also be used for pulp production. Biomass residues, such as rice straw, are used in pulp and paper industries in developing countries, particularly Algeria, Argentina, China, and India. The production of pulp from rice straw and other non-wood fiber increased from 16.5 million tons in 2003 to 18.4 million tons in 2007 (FAO, 2012) that the main products of this industry include corrugated medium, board, and packaging paper. China produces more than 9 million tons of straw pulp from rice straw, which is covered with wax particles in the process (Peng et al., 2010). The generation of strong wastewater because of low yield values is one of the most important limiting factors in the development of rice straw pulp production. Almost 50% of raw materials are wasted in the pulp production process (Rodriguez et al., 2010).

Several studies have investigated the application of rice straw to mushroom cultivation (Shashirekha et al., 2002; Das and Mukherjee, 2007; Yu et al., 2010; Williams et al., 2013). The main problem of mushroom cultivation on rice straw is the low yield during the different steps of the cultivation period (Das and Mukherjee, 2007).

Rice straw can also be used for the extraction of valuable chemicals, including 5-hydroxy methylfurfural and furfural, which are used for the production of fuel, glucose, bio-ethanol, xylose, glucan, and methane (Liu et al., 2007; Amiri et al., 2010; Hsu et al., 2010; Chen et al., 2011a; Chandra et al., 2012).

Composting, which is a commonly used for the disposal of plant residues, offer many advantages, including sanitation, volume reduction, and improvement of characteristics, such as a decrease in C:N (Abdelhamid et al., 2004). However, composting requires long process time, large space, and manpower (Raut et al., 2008). The conventional composting process needs to a long time, 2-6 months, for processing of biotransformation of raw materials to maturated compost. Therefore decreasing of composting process time is an interesting topic for research (Lin et al., 2009).

Different study has evaluated vary parameter in order to shorten of composting period or reach to optimum stability. Influences of rock phosphate and *Aspergillus Niger, Trichodermaviride*, fresh buffalo’s manure and 10% (w/w) of rock phosphate, mixture of shredded and non-shredded rice straw and sewage sludge, the effect of quantity and particle size of rice straw and mixing of fresh farmyard manure and effect of poultry manure and oilseed rape cake on rice straw composting was studied. As a general conclusion the composting period was too long, around 90 days and need to use other process for decreasing of rice straw composting (Abdelhamid et al., 2004; Zayed and Abdel-Motaal, 2005; Hatem et al., 2009; Roca-Pérez et al., 2009; Rashad et al., 2010). However, influences of a consortium of *Aspergillus Niger (F44)* and *Trichodermaviride (F26)* studied on decomposition of rice straw (Kausar et al., 2010). The results demonstrated that the fungal consortium was able to reduce the composting period less than 3 weeks. The C:N ratio declined from 29.3 to 19.5 in the composting process period. Performance of rapid composting with fungi and enzyme pretreatment is a costly and time consumes method (Mtui, 2009). Influence of different parameters on composting of MSW carried out in studies. An investigation was performed on rapid composting of MSW. The results show using of aeration, addition of glucose and acetic acid and application of cellulolytic microbial enhanced composting process and reduction composting process time around 9-12 days (Raut et al., 2008). Likewise, continues thermophilic composting was able to reduction of MSW composting period to 14-19 days (Xiao et al., 2009).

2.3 Composting process

Composting is an aerobic biological process used for transforming solid waste into valuable and stable organic matter that is considered environmentally friendly and economical. Unstable organic matter rapidly mineralized into stable compounds during the composting process (Wei et al., 2007; Tejada et al., 2009b).

The bio-oxidation process can only process soluble compounds with low molecular weight (Jördening and Winter, 2005). Therefore, complex-structure organic matter is broken down into simple water-soluble substrates in the composting process because of the enzymes released by microorganisms (Castaldi et al., 2008).

The conversion of rice straw into value-added compost may possibly improve the productivity of crops, reduce environmental pollution, and avoid local pollution caused by open-burning (Zayed and Abdel-Motaal, 2005; Roca-Pérez et al., 2009). Temperature, oxygen, and moisture are the three most significant factors in the composting process (Ruggieri et al., 2008).

In composting, carbonaceous compounds hydrolyzed into organic acids and then oxidized with CO_2 and heat (Chang et al., 2006). Microorganisms use readily degradable OM as a source of C and N. The resultant compost consists of the following elements: transformed, slowly degradable compounds; intermediate breakdown products; and cell walls of dead microorganisms (Wei et al., 2007). Some of the advantages of composting include sanitation, mass and bulk reduction, and decrease in C:N (Zayed and Abdel-Motaal, 2005). However, composting requires long process time, large space, and manpower (Raut et al., 2008).

Non-readily biodegradable compounds of rice straw, such as lignin, are resistant to biological conversion. The low reaction rate of the biological process in the decomposition of lignocellulose-containing materials, such as rice straw, increases the composting process time (Zayed and Abdel-Motaal, 2005). The aerobic biotransformation reaction can be expressed using Equation 2.1 and Figure 2.3:

$$(C_6H_{10}O_4)_x + 6.5O_2 = (C_6H_{10}O_4)_{x-1} + 6CO_2 + 5H_2O \qquad (0.1)$$

The energy balance between raw materials and end products indicates that the aerobic biotransformation reaction is a self-heating reaction. Bio-oxidation of one mole of glucose ($C_6H_{12}O_6$) to the end product produces 73 kcal of heat (Themelis et al., 2002).

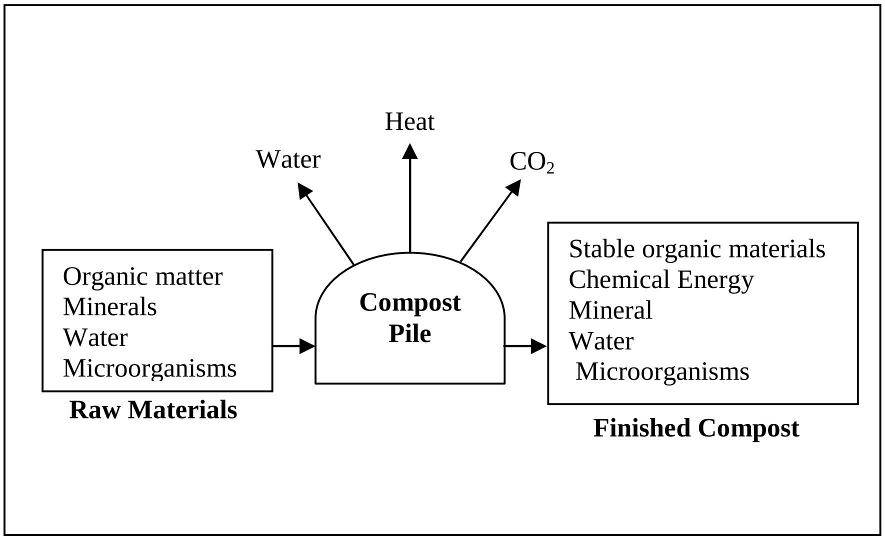

Figure 2.3: Scheme of composting process (source: Themelis et al., 2002)

Cattle manure is a natural soil fertilizer resource that provides the necessary elements for crop growth and represents a low-cost alternative to mineral fertilizers (Gómez-Brandón et al., 2008). Rice straw is rich in C but poor in both N and moisture. The C:N of rice straw can vary between 50 and 150, limiting the composting process (Abdelhamid et al., 2004). Mixing cattle manure and rice straw can provide suitable C:N and moisture content (MC) as well as more balanced nutrients for the microorganisms to perform decomposition(Li et al., 2008).

Table 2.4Table 2.4 shows the physicochemical characteristics of rice straw and cattle manure, which are typically used as feedstock in some related studies.

Table 2.4: Selected physicochemical properties of feed stock of composting process

Parameters	Rice straw (mean)					Cattle manure (mean)			
MC, %	10.87[a]	-[b]	5.50[c]	12.7[d]	8.80[e]	73.49[c]	-[f]	82.00[e]	-[g]
OM, %	87.91	-	82.85	80.3	88.30	76.60	-	84.40	-
TOC, %	48.84	39.4	48.05	-	40.6	44.42	65-126	43.30	39.90
TKN, %	0.55	0.64	0.53	0.93	0.77	2.06	4.2-8.1	1.60	2.40
C:N	88	61.3	76.27	46.80	52.70	21.50	-	27.10	17
pH	7.18	7.20	7.10	-	-	7.50	8.60	-	8.26
EC, (dS m^{-1})	1.91	3.58	2.67	-	-	1.32	-	-	1.30

[a] Petric et al., 2009b
[b] Abdelhamid et al., 2004
[c] Roca-Perez et al., 2009
[d] Iranzo et al., 2004
[e] Tang et al., 2004
[f] Bernal et al., 2009
[g] MarıaGomez-Brandon et al., 2008

2.3.1 Role of composting process on treatment of solid waste

In composting, organic wastes are bio-transformed into minerals and stable compounds under controlled aerobic conditions. Application of untreated solid waste to agriculture leads to the following adverse effects:

Undesirable reactions: Readily biodegradable fractions of organic matter consumes under anaerobic conditions. The end products of anaerobic bioconversion, such as ammonia, hydrogen sulfide, and methane, may be toxic to plant growth and cause odor problems.

Depletion of nutrients in soil: Introducing large amounts of untreated substrates to agricultural farms leads to an increase in microorganism population, which decomposes organic matter. Carbon, nitrogen, and phosphorus are essential elements for cell biomass production. Therefore, an increase in microorganism population leads to a sharp decline of such elements, particularly nitrogen, in soil. Consequently, plants cannot obtain sufficient quantities of required elements.

Leaching of toxic materials: Soil and water resources may be polluted by untreated solid waste containing toxic materials, such as heavy metals, microbial pollution sources, and alkali and acid compounds (Iranzo et al., 2004; Pichtel, 2005). Final composts serve as agricultural farm soil conditioners, supply nutrients (N, P, and S) and micronutrients (Cu, Fe, Zn, and Ni) to plants, act as daily covering for landfill, and function as media for bioremediation of heavy metals from soil (Pichtel, 2005).

2.3.2 Classification of compost

The composting process performs differently under varying conditions. With regard to composting reaction, condition, or employed technology, the composting process is classified into anaerobic and aerobic; mesophilic and thermophilic; and windrow, aerated static, and in-vessel (Deportes et al., 1995; Komilis, 2003; Diaz et al., 2004).

Aerobic composting is accomplished with the presence of sufficient oxygen. On the other hand, the concentration of oxygen in anaerobic composting is lower than the limited concentration. Solid waste management usually prefers aerobic conditions. In composting, providing aerobic conditions in all parts of the organic feedstock in a full-scale plant is very difficult and expensive (Diaz et al., 2004).

In a normal compost of solid waste, an increase in temperature is an index of the start of the process. This increase in temperature can be attributed to the bio-oxidization of readily biodegradable compounds, such as sugar, starch, and protein, by using mesophilic microbes. High temperatures provide suitable conditions for the development of a thermophilic microbe population (Deportes et al., 1995). Pathogenic microorganisms, weed seeds, and a large part of complex compounds are decomposed under thermophilic conditions.

Temperature decreases because of a lack of available carbon content substrates in the composting pile. Consequently, nitrifying bacteria develops to convert phytotoxic ammonium-nitrogen to nitrate. In this phase, the composting materials become stable and mature (BSI, 2002; Diaz et al., 2004). Bacteria are developed during the initial stages of composting, whereas fungi and *actinomycetes* are the dominant species during the end of the composting process (Komilis, 2003).

Mesophilic conditions accrue in a temperature range of approximately 5 °C to 45 °C. However, the proper temperature in thermophilic conditions ranges from 45 °C to 75 °C (Diaz et al., 2004).

In general, compost systems fall into two groups of windrow and in-vessel (Diaz et al., 2004) or into three groups of windrow, aerated static, and in-vessel (Komilis, 2003). In a Windrow system, organic wastes are placed in long and controlled crosssectional size piles, which promote the complete aeration of the composting mass and dispersion of moisture and microorganisms. Windrow processes may be accomplished under shelter or on an open area. Shelters help control operational factors, such as moisture and temperature, during winter or rainy season. The windrow piles are turned at times either by hand or by turner machine. Ideal piles have heights ranging from 1.2 m to 2.4m and widths ranging from 4.2 m to 4.9 m. Such piles can capture the temperature and heat. Almost all kinds of organic waste can be processed in windrow process. Leaching, odor, and pollution caused by heavy metals are three important concerns associated with such method (Komilis, 2003; Diaz et al., 2004; EPA, 2012b). Plate 2.3 and Plate 2.4 show the windrow piles and a simple model of a windrow turner.

Plate 02.3:Windrow composting piles
(Source: www.greeneng.co.za/Gallery.html)

Plate 02.4: A model of Windrow turner
(Source:www.globalrepair.ca/507turner.htm)

In an aerated static system, piles of chopped organic solids are mixed with a sufficient bulking agent (i.e., wood chips or shredded newspapers) and then placed on a network of perforated piping, which is installed in a channeled concrete floor. The rigid piping is connected to a series blower or vacuum pump. This system offers the advantages of controlled aeration level, temperature, moisture, and odor through a fan connected to bio-filters. No mixing and turning are done, and thus, the operator should ensure that uniform temperature and aeration predominate on the composting mass (Figure 2.4). The aeration system is controlled using a timer or temperature sensors. The aerated static system suitably processes homogenous organic wastes (Komilis, 2003; EPA, 2012b).

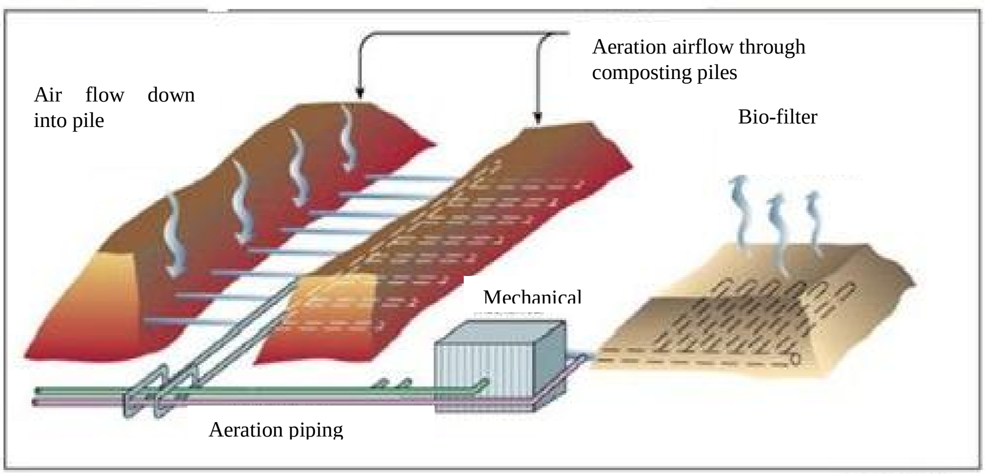

Figure 2.4: Schematic of aerated static pile
(Source:www.sonomacompost.com/changes.shtml)

In an in-vessel system, organic materials are loaded into an often large cylindrical container, such as a drum, silo, concrete-lined trench, or similar equipment, which provides closely controlled conditions (i.e., of temperature, moisture, and aeration rate) to achieve a high rate of composting (Plate 2.5). Capacity and size vary in an in-vessel system, which is usually associated with high capital costs. The in-vessel system is typically combined with the windrow system to reduce capital and operation costs. In such combination, the composting process is conducted in the in-vessel and then the compost is fed to the windrow system for the maturation phase.


Plate 20.5: Two images of in-vessel composting (Source: www.caes.uga.edu/publications; www.cee-environmental.com/en/company/products/page/5)

The advantages of the in-vessel system over the windrow or aerated static systems include highly controlled environment, non-dependency to environmental conditions, and few requirements in terms of manual labor and land. Higher capital and operation costs and a need for expert operators are the disadvantages of the in-vessel system (Komilis, 2003; EPA, 2012b).

Comparing the energy consumption of the three systems, the windrow process requires the least energy with 21.4 kWh/ton MSW, whereas the aerated static piles and in-vessel systems require 25.2 and 30.0 kWh/ton, respectively (Komilis, 2003).